BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 11020

SUBJECT: Revisions to the BCMASP Earth-Orbit Simulator Program - Case 610

DATE: November 10, 1969

FROM: A. B. Baker

ABSTRACT

The BCMASP Earth-Orbit Simulator is a special purpose computer program designed to generate and analyze long-duration earth-orbital spacecraft ephemerides. The EOS has five principal computational options. It can be used to compute

- the spacecraft ephemeris
- the spacecraft day/night cycles
- site visibility for photographic targets
- line-of-sight encounters with MSFN ground stations
- an optimum powered flight trajectory.

On option, the EOS will also generate a magnetic tape containing the descriptions of spacecraft-target encounters. The tape can be used with either the photographic or communications options and is designed to be used as the primary input to the Target Site Analysis Program. The latter is an auxiliary program developed specifically to analyze a series of spacecraft-target encounters.

The simulator retains the overall structure of the standard BCMASP; however, a number of significant modifications were made to the latter to facilitate the accomplishment of the computational objectives. These include:

- modification to 21 of the "standard" BCMASP subroutines
- modification to the common and input data structures
- addition of four original subroutines to the output processor
- use of special Events and Print Lists.

417

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MEMORANDUM FOR FILE

1.0 Introduction

The BCMASP Earth-Orbit Simulator (EOS), described in References 1-3, has been modified to run on the UNIVAC 1108 EXEC 8 system. In addition, other changes have been made to the program which expand its capabilities and increase its operational flexibility. These modifications, described below, fall into one of two categories:

(1) those affecting the general operation of the program, and

(2) those affecting the simulation and analysis of the orbital trajectory.

2.0 Operation on the UNIVAC EXEC 8

The EXEC 2 version of the Earth-Orbit Simulator is a complete, self-contained version of BCMASP. Though it performs satisfactorily, it does not contain many of the computational improvements made to BCMASP subsequent to its inception. To take advantage of these as well as future improvements, the EXEC 8 version of the simulator has been made completely compatible* with the EXEC 8 version of BCMASP. The former now consists of only 25 subroutines. Four of these subroutines are original; the remaining 21 are modified versions of "standard" BCMASP routines. The symbolic and relocatable elements of these 25 routines, along with a MAP to segment the program and five card file elements to facilitate operation of the EOS are stored on a read-only FASTRAND file named BCMASP*DIX1. Its contents are shown in Table 1.

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*i.e., a majority of the subroutines used by the EOS are taken directly from the BCMASP library.

Operation of the EOS requires the assignment of four files for the duration of the run. In addition to BCMASP*DIX1, it requires

BCMASP*ASP	the standard BCMASP program file
BCMASP*EPHEMERIS	a data file containing the ephemerides of the earth, sun, and moon
BCMASP*QFILE	a temporary or scratch file used only during the run for the periodic recording of rollback data.

An intermediate file or tape must also be assigned if the PRINT LATER or PRINT BOTH options are used.

The MAP on BCMASP*DIX1 defines the manner in which the EOS is to be segmented during execution. A listing of this MAP appears in Figure 1. The MAP defines four segments. Three segments (SETUPG, PROCSS, and SIMDKS) each contain subroutines (or elements) which are used exclusively by that segment. Specifically, SETUPG contains all of the setup and initialization routines, SIMDKS contains those elements used only for the generation of the spacecraft trajectory and PROCSS contains the data processing routines that control the execution of the Print List. The MAIN segment contains the subroutines common to the other three segments.

Proper operation of the Earth-Orbit Simulator requires that the 21 "modified" subroutines on BCMASP*DIX1 be used in place of the respective standard versions that appear on the BCMASP program file. To insure that these subroutines are indeed used, the entire contents of the BCMASP*DIX1 file are copied onto the Temporary Program File TPF$. When a subsequent command is encountered to execute the MAP, the collector will use the version of the element on TPF$ instead of the corresponding version on BCMASP*ASP.

As discussed in Reference 1, the EOS Print List is constructed specifically to compute site visibility for photographic targets. However, it can easily be modified to perform a number of other computations related to the spacecraft trajectory (e.g., spacecraft day/night cycles* and line-of-sight encounters with MSFN ground stations**). Since the precompiled

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*Reference 3

**Section 3.2

version of the Print List (Subroutine OUTTGT) is stored on the EOS program file, these modifications can most easily be accomplished by editing the subroutine before the program goes into execution.

The required edits for each of five commonly used computational options are stored on BCMASP*DIX1 as card file elements and can be inserted at the appropriate place in the run stream by use of an ADD statement. To further facilitate the use of the program, each element also contains control cards which assign the necessary files and direct the use of the MAP contained on BCMASP*DIX1. Hence, to use the EOS one simply assigns file BCMASP*DIX1 and adds the appropriate card file element to the run stream. The name and function of each card file element are listed in Table 2.

2.1 Addition of COMMON Block CEOS

One of the primary problems in structuring the EOS to be compatible with the standard BCMASP is the assignment of COMMON locations to working variables which are unique to the EOS. Originally, these working variables were always assigned to COMMON locations listed as vacant (or unassigned) by the TAGS dictionary for the standard version of BCMASP. However, the subsequent use of these locations in the standard version produced conflicts and necessitated the reassignment of the EOS variables to other vacant locations. To maintain compatibility therefore, the EOS working variables had to be reassigned every time conflicts occurred.

To provide a more permanent solution, a new labeled COMMON block named CEOS was created which contains one singly dimensioned array, EOS(50). These 50 words may also be given individual names by use of the EQUIVALENCE statement. The assignments made thus far are listed in the Appendix. CEOS was integrated into the COMMON structure by

(1) modifying the TAGS dictionary to include CEOS and its array EOS(50). The dictionary does not, however, include any of the specific tag names listed in the Appendix; hence input data cards must name specific elements of the EOS array, e.g.,

EOS(7) = 2

which enters the integer 2 into EOS(7).

(2) modifying Subroutine PRTCOM so that COMMON dumps will include the EOS(50) array.

(3) modifying the routines designed to write and read the rollback tape and the intermediate tape so that the EOS array is treated in parallel with the VAR array, e.g., the two arrays are always written and read together. It should be noted that when the shortened form of the intermediate tape record is used during long-term ballistic flight (described in Reference 3) only nine words of the VAR array will be transmitted to the output processor in a PRINT LATER run. Transmission of the EOS array is suppressed along with all other VARs.

In BCMASP all variables are stored in COMMON to facilitate their centralized management. To accomplish this objective the complete structure of COMMON must be known and used by many of the standard BCMASP routines. To minimize the changes to standard routines, however, the following simplifications were made in adding CEOS.

(1) The precompiler was not modified to automatically include the CEOS block in the COMMON statements. Therefore, any Events List or Print List that references these variables must include the necessary additional COMMON, DIMENSION and EQUIVALENCE statements.

(2) Subroutine LODCOM was not modified. Therefore the contents of EOS(50) are not initialized for any run other than the first. The latter is provided by the system.

2.2 Construction of the EOS Job Deck

A sample EOS job deck is shown in Figure 2. The data for an EOS run is divided into two sections. The first section contains all of the data pertaining to the program's operation and to the simulation of the spacecraft trajectory (e.g., mode card, print card and the basic set of variables required to initialize the simulator) while the second section contains all data pertaining to spacecraft-target encounters as well as solar prediction data used in the generation of the dynamic drag model (Reference 2).

The EOS can be operated in either the TARGET or OPEN mode. The TARGET mode provides the capability to iteratively select a powered flight trajectory that achieves specified insertion conditions. It is rarely used and will not be described here. OPEN mode operation is the more usual way to use EOS, where conditions at insertion are supplied as input data. A single Events List was designed to be used for both applications. It was precompiled and compiled with the name SIMTGT. To avoid duplicating this program under the SIMOPN name, an abbreviated SIMOPN is provided whose only function is to transfer control to SIMTGT when SIMOPN is called in an OPEN mode run. The PRINT NOW or PRINT LATER options may be used with either mode; however it appears that the PRINT LATER option offers no advantage in running time or required core space and is not recommended.

The data for an OPEN mode run (which runs from Event S4OFF1 to Event STOP) is divided between the two sections of the data deck. The first section contains the basic set of variables required to initialize the simulator at S4OFF1; i.e., RIX(3), VIX(3), T, TIMEO, DATEO, TC3, EOS(4), EOS(5), and EOS(6). Optional data to control the special maneuvering events (described in Section 3.1) may also be included. The first section of the data deck ends with a LAST card which terminates the setup phase of the program.

The second section of the data deck is used to initialize two special data blocks that have been created in COMMON, but are separate from the BCMASP COMMON structure. These labeled COMMON blocks, BAKER and NASH, are used to store input data for the exclusive use of subroutines OUTTGT and DYNAMC respectively. Their contents are listed in Table 3.

The second section is itself divided into two subsections. In the first subsection all of the required data, with the exception of the cards describing the specific targets to be investigated, is read in under a NAMELIST named INPUT. Hence the first data card of the second section is a $INPUT card. All data to be specified in this subsection may be read in after the $INPUT card in any desired order in equation form. The last data card in this subsection must be followed by a $END card.

If the run requires information on terrestrial targets, the cards containing the characteristics of the target sites are placed in the second subsection immediately following the $END card. Each card is arranged as follows:

Columns 1-18	Name of the target site
Columns 19-26	Geodetic latitude of the target site
Columns 27-34	Longitude of the target site.

Any alphanumeric characters may be entered in the first 18 columns; the values of latitude and longitude however are floating point decimals. An END card must follow the last target site card.

2.3 Generation of Spacecraft-Target Encounter Tape

An option has been included in the EOS to generate a magnetic tape containing the descriptions of spacecraft-target encounters. The tape can be used with either the photographic or communications analysis options and is designed to be used as the primary input to the Target Site Analysis Program* (TSAP). The latter was developed specifically to analyze a series of spacecraft-target encounters. TSAP generates a printer-plot of the encounters with elapsed mission-time as the abscissa and the duration of encounters as ordinate. The plot will also indicate overlapping contacts, the current local time of encounter (day, evening, or night) and, for MSFN stations, the type of data transmission capability available (record and/or real time).

Two alterations to the EOS job deck are required to generate the tape. First, the tape number must be assigned to logical unit 8 in an ASG (assign) statement immediately preceding the ADD statement (Figure 2). In addition, the variable IPLOT must be set equal to either 1 or 2 in the second section of the data deck. Setting IPLOT equal to 1 permits the tape to be generated but suppresses the printing of the descriptions of the spacecraft-target encounters in the EOS run. When IPLOT is set equal to 2, both the tape and the printout are generated.

3.0 Changes Affecting the Simulation and Analysis of the Orbital Trajectory

3.1 Simulation of Orbital Maneuvers

The EXEC 2 version of the EOS contains only one event, Event STOP, following the orbital insertion event, S4OFF1. The criterion for executing Event STOP is a value of mission elapsed time, input by the user, which defines the required duration of the orbital simulation. The user therefore has no control over the orbital trajectory subsequent to the insertion event.

---

*Reference 4

Missions may, however, be considered a series of phases, bounded by specific spacecraft maneuvers with each maneuver having a significant effect on the spacecraft trajectory. These maneuvers include:

(1) the docking (or undocking) of two spacecrafts (a Workshop and a CSM) which, by changing the physical characteristics of the orbiting mass (overall weight and cross-sectional area), changes the rate of orbital decay, and

(2) an orbit change (via a Hohmann or minimum energy transfer) of the orbiting vehicle. This maneuver will be required at the beginning of the mission and again whenever the altitude of the orbiting vehicle decays sufficiently to either subvert the mission objectives or to pose the danger of unplanned reentry.

To simulate these two maneuvers, five new events were added to the EOS Events List. All five will occur during the simulation of the orbital trajectory, that is, after the execution of Event S4OFF1 and prior to the execution of Event STOP. This portion of the EOS Events List is shown in Figure 3.

The docking maneuver is simulated by Event DOCK. The event is executed when the mission elapsed time is equal to TDOCK. At the event, the weight, drag coefficient, and cross-sectional area of the orbiting mass are redefined to reflect the changes to the orbiting mass. The new values of weight (WGTDOK), drag coefficient (CDDOK), and cross-sectional area (ARADOK) as well as the value of TDOCK are specified in the data deck.

An orbit change is simulated by a sequence of four events. Their relation to an actual Hohmann transfer is illustrated in Figure 4. In the figure, Point O represents the center of the earth and Lines OB and OC represent the perigee and apogee distances of the original orbit. The sequence is initiated by Event SRCH1 (Point A) which is executed when the mission elapsed time is equal to TSRCH1, an input value. A minimum energy transfer requires that the spacecraft velocity be redefined only at the apsides; hence Event SRCH1 initiates a search for the next apsis (shown as the perigee point B in Figure 4). Beginning with Event SRCH1, the cosine of the angle between the spacecraft's radius and velocity vectors is calculated at every integration step. The apsis is then the point at which the two vectors are perpendicular.

Event BOOST is executed at the apsis (Point B). At that event, the value of orbit radius required at the end of the transfer is input to Subroutine ALTER which redefines the spacecraft velocity vector. This new velocity vector together with the spacecraft position vector defines the spacecraft orbit as the transfer ellipse BDE.

If the spacecraft's orbit is to be modified further, e.g., circularized, then the modifications will be performed at Point E (Event CIRCLE). Event SRCH2 initiates the search for Point E. As in the case of Event SRCH1, the time of execution of Event SRCH2 is not of primary concern so long as it occurs sometime before the spacecraft reaches Point E. Therefore, the execution time of Event SRCH2 has been chosen as the mission elapsed time corresponding to 10 minutes prior to the spacecraft's estimated arrival time at Point E (Point D in Figure 4). The estimated arrival time at Point E is found by adding one-half the Keplerian period of the transfer ellipse to the mission elapsed time at the execution of Event BOOST.

In order to determine the location of Point E, a vector $\overrightarrow{OF}$ is defined at Event SRCH2 (Vector TTEMP in the Events List). It is contained in the orbit plane and perpendicular to the spacecraft radius vector $\overrightarrow{OB}$ at the perigee point B (Vector RSAV in the Events List).* The dot product of $\overrightarrow{OF}$ and the current spacecraft radius vector $\overrightarrow{OR}$ (RX in the Events List) is defined as R_T. Since R_T is the magnitude of the projection of $\overrightarrow{OB}$ onto $\overrightarrow{OF}$, R_T will be equal to zero when $\overrightarrow{OR}$ is perpendicular to $\overrightarrow{OF}$. Hence we can define the criterion for the execution of Event CIRCLE, which is to be executed at Point E, as $R_T = 0$.

The spacecraft orbit is circularized at Event CIRCLE. Since the circularization can be considered as a type of orbit change it can be simulated by the same techniques used to simulate the Hohmann transfer; i.e., using Subroutine ALTER to redefine the spacecraft velocity. This time however the required orbit radius at the end of the next half-orbit is the same as the current value (the value at Point E). Hence the input to Subroutine ALTER is the current magnitude of orbit radius.

---

*$\overrightarrow{OF} = (\overrightarrow{OB} \times \overrightarrow{OR}) \times \overrightarrow{OB}$

As mentioned above, Subroutine ALTER was used at Event BOOST and Event CIRCLE to determine the new spacecraft velocity. The subroutine can in fact be used at either apsis to define the current spacecraft velocity required to achieve any desired orbit radius one-half orbit later. The calculations performed in Subroutine ALTER are based upon the analysis reported in Reference 5 which showed that "when tangential burns are used in earth orbit to achieve a specific radius one-half orbit later, a significant error in that radius will occur if the velocity achieved with the burn does not include a component to compensate for the earth's asphericity." The report also showed the magnitude of the required correction to the Keplerian velocity is a function of the apogee and perigee radii, the orbital inclination, and the geocentric latitude of the spacecraft's subpoint at the time the burn is made. The complete expression for the required velocity is shown in Reference 5 to be

$$V_{req}^{\,2} = V_c^{\,2}\left\{1 + \frac{J}{3}\left(\frac{R_e}{r_1}\right)^2\left[1+\rho+\rho^2-2\rho^2\sin^2 i - \sin^2\phi_i(3+3\rho-\rho^2)\right]\right\}$$

where

$$V_c^{\,2} = \frac{2\mu r_m}{r_i(r_i+r_m)}$$

$$\rho = \frac{r_i}{r_m}$$

and

- i = orbital inclination
- J = the first harmonic of the earth's gravitational potential
- R_e = equatorial earth radius
- r_i = spacecraft radius at the time of burn
- r_m = desired spacecraft radius one-half orbit after the burn
- V_{req} = velocity required to achieve the desired spacecraft radius one-half orbit later
- μ = Earth's gravitational constant
- ϕ_i = geocentric latitude of the spacecraft's subpoint at the time of the burn.

This expression is used in Subroutine ALTER to solve for the magnitude of the required spacecraft velocity. The latter is then resolved into its axial components by forming the product of the new magnitude with each of the direction cosines of the original velocity.

The Events List in Figure 3 was used to simulate the orbital maneuvers of a typical AAP mission. After 3-1/3 days in orbit the spacecraft was transferred from its original 185 x 210 nm orbit to an altitude of 212 nm. The orbit was circularized at 212 nm. Figure 5 illustrates the results of the simulation. It is a plot of the variation of the spacecraft radius (converted for convenience to geocentric altitude) with time and shows the accuracy of the actual orbit to be within one mile of the desired value.

It should be noted that the user has the flexibility to simulate either or both of the orbital maneuvers without modifying the Events List. The execution of Event DOCK and of Event SRCH1 (which initiates the simulation of the Hohmann transfer) are determined by the input values of mission times TDOCK and TSRCH1 respectively. If either (or both) of these values are not specified in the data deck, they are set equal to zero. Since an orbital simulation which begins at insertion (Event S4OFF1) has an initial value of mission elapsed time greater than zero, the criterion can never be satisfied and the event will not be executed.

3.2 Computations of Line-of-Sight Contact for MSFN Ground Stations

As mentioned above, the EOS Print List is constructed specifically to compute site visibility for photographic targets. However, a slightly modified version of the same algorithm can be used to compute line-of-sight contact for MSFN ground stations.

The viewing geometry which is the basis for the EOS algorithm that determines acceptable visual contacts with a photographic site* is shown in Figure 6a. In the figure, S represents the spacecraft and P its subpoint on a spherical earth whose center is at Point O. Point A represents the position of a terrestrial target. An acceptable contact is established when the viewing angle θ, defined by the relative position of the spacecraft and the site, is less than some fixed value α.

---

*Described in detail in Reference 1.

Though the criterion for line-of-sight contact with an MSFN ground station is usually specified in terms of the spacecraft's elevation angle, it can also be specified in terms of the viewing angle α. The viewing geometry for the determination of an acceptable line-of-sight contact is shown in Figure 6B where the points A, O, P, and S, and the angles α and θ have the same meaning as in Figure 6A. As in the case for photographic site encounters, an acceptable line-of-sight contact is established when the viewing angle θ is less than α. In this case however, the value of α is not constant but is defined at each point in the trajectory as

$$\alpha = \sin^{-1}\left(\frac{R_e}{R}\cos\beta\right)$$

where

R_e is the earth's radius (Line OC)

R is the spacecraft radius (Line OS)

β is the limiting value of spacecraft elevation angle.

A card file element (COMMUN) which incorporates the necessary changes to redefine α (according to this latter definition) at succeeding points in the spacecraft trajectory has been added to BCMASP*DIX1 and can be used as described in Section 2.0 to generate a list of line-of-sight contacts with MSFN ground stations. The station's characteristics are input to the program in exactly the same manner as the characteristics of the photographic sites.

4.0 Summary

The BCMASP Earth-Orbit Simulator has been revised to achieve compatibility with the EXEC 8 version of BCMASP. The EXEC 2 version of the EOS is a complete self-contained version of BCMASP. The new version however consists of only 25 subroutines, 21 of which are modified versions of standard BCMASP routines. Proper operation of the EOS requires that the 21 modified subroutines be used in place of the respective standard versions that appear on the BCMASP program file.

Many of the problems in maintaining compatibility between the standard BCMASP and the EOS arise from the recurring conflicts which occur in the assignment of COMMON locations. To eliminate these conflicts, a new COMMON block with 50 locations was created specifically for working variables unique to the

EOS. The new block is fully integrated into the program structure and offers the user the same flexibility available to him with the Simulator Working Variables (VARs).

The EOS now has five principal computational options. It can be used to compute

- the spacecraft ephemeris
- the spacecraft day/night cycles
- site visibility for photographic targets
- line-of-sight encounters with MSFN ground stations
- an optimum powered flight trajectory.

The operation of the EOS has been simplified by the creation of a card file element for each computational option. Each element contains the necessary control cards and edits to the precompiled Print List to run one of the options. The five card file elements are on the EOS program file and can be added to the run stream by use of an ADD statement.

On option, the EOS will also generate a magnetic tape containing the descriptions of spacecraft-target encounters. The tape can be used with either the photographic or communications options and is designed to be used as the primary input to the Target Site Analysis Program. The latter is an auxiliary program developed specifically to analyze a series of spacecraft-target encounters.

The EOS Events List can simulate two orbital maneuvers which affect the spacecraft trajectory: docking and a minimum energy (Hohmann) orbit transfer. Docking is simulated by Event DOCK. At that event, the weight, cross-sectional area, and drag coefficient of the orbiting mass are redefined to reflect the change in the orbiting configuration. The Hohmann transfer is simulated by a sequence of four events which is initiated by Event SRCH1. The latter initiates a search for the nearest apsis which is found when the spacecraft's radius and velocity vectors are perpendicular. The spacecraft velocity is redefined at the apsis so that the spacecraft travels on a transfer ellipse and arrives at the desired altitude one-half orbit later. The orbit is circularized at that point by the same technique, i.e., redefining the spacecraft velocity.

The execution of each maneuver is controlled by an input value of mission elapsed time. By specifying a value in the input data deck the user controls not only the time at which the maneuver is performed but whether it is performed at all. If a value of mission elapsed time is left unspecified, the corresponding maneuver will not be performed.

Acknowledgment: The author wishes to express his appreciation to Mr. P. H. Whipple for his suggestions on the implementation of the techniques described in Reference (5) and to Miss D. P. Nash who helped with the programming.

1025-ABB-dcj

A. B. Baker

Attachments

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"Computation of Ground Site Visibility from Orbit"
Bellcomm TM 68-1025-1 May 16, 1968

2. A. B. Baker
"Application of a Dynamic Density Model to the Simulation of Earth Orbit Trajectories"
Bellcomm TM-68-1025-2 September 23, 1968

3. A. B. Baker
"Changes to the BCMASP Earth-Orbit Simulator"
Bellcomm B69-02001 February 3, 1969

4. D. P. Nash
"TSAP - A Target Site Analysis Program"
Bellcomm Memorandum for File, September 30, 1969.

5. P. H. Whipple
"A Modified Perigee and Apogee Velocity Expression to Reduce Radius Errors Caused by the Earth's Asphericity"
Bellcomm TM-69-1025-1 July 14, 1969

```
LIB     ASP.
SEG     MAIN
IN      ASP.CTLUNV
IN      C1,C2,C3,C4,C5,C6,C7,C8,C9,C10,C11,HEAD,EVTAB,;
        TABLE1,TABLE2,TABLE3,TABLE4,TABLE5,TABLE6,CFIG,CEOS
SEG     SETUPG*,(MAIN)
IN      ASP.SETUPG
SEG     PROCSS*,SETUPG
IN      ASP.PROCSS
SEG     SIMDKS*,PROCSS
IN      SIMDKS
```

FIGURE 1

MAP for the BCMASP Earth-Orbit Simulator

FIGURE 2

Sample EOS Job Deck

```
@RUN
@HDG                 Sample EOS Job Deck
@ASG,A               BCMASP*DIX1
@ASG,TM              2,T,[Intermediate tape number]R
@ADD                 BCMASP*DIX1•[Card file element name]
 [                           ]
 [    Data Deck - Section 1  ]
 [                           ]
 LAST
 [                           ]
 [    Data Deck - Section 2  ]
 [                           ]
 [ $INPUT                    ]
 [     .                     ]
 [     .                     ]
 [     .                     ]
 [ $END                      ]
 [                           ]
 [   Target Cards            ]
 [                           ]
 END
@FIN
```

```
EQUFOR C1,C2,C3,C7
      SUBROUTINE SIMTGT
C
      COMMON/CEOS/EOS(50)
C
       EQUIVALENCE  (EOS( 3),TB), (EOS( 4),CDINJ), (EOS( 5),ARAINJ),
     . (EOS( 6),WGTINJ),   (EOS( 7),CDDOK),  (EOS( 8),ARADOK),
     . (EOS( 9),WGTDOK),   (EOS(10),TDOCK),  (EOS(11),TSRCH1),
     . (EOS(12),ALT1) ,   (EOS(18),GINCL) ,   (EOS(21),QMAX) ,
     . (EOS(26),RAPOGR) ,   (EOS(40),IDATA)
C
       DIMENSION  RSAV(3),  QTEMP(3),  TTEMP(3)
C
 EVENT S4OFF1(JETLES)
 CRITERION(V=VOFF)
      V=VALUE(VX)
      ITHR=0
      OMEGAY=0.
      OMEGAP=0.
      TSAV=T+TC3
      BETAI=BETA(RX,VX)
C
C
       CALL CROSS(RX,VX,HX,1)
       CALL ROTEQ(0,HX,HTX)
       GINCL=RTOD*ATAN2(SQRT(1.-HTX(3)**2),HTX(3))
C
C
       ISUN=1
       IMOON=1
       CALL ENCKE(0)
       IOBLAT=1
       H=60.0
       HNORM=60.0
       HR=0.0
       HSMAX=0.0
       INTINC=1
       TB=T+H
       IDRAG=2
       WGT=WGTINJ
       CD=CDINJ
       XAREA=ARAINJ
C
C
 AUXEQ
       IF(T.GT.TB)  IDATA=1
C
C
 EVENT DOCK  (S4OFF1,STOP)
 CRITERION (T=TDOCK)
C
       WGT=WGTDOK
       CD=CDDOK
       XAREA=ARADOK
 AUXEQ
C
C
 EVENT SRCH1 (S4OFF1,BOOST)
 CRITERION (T=TSRCH1)
C
C
C
 AUXEQ
      V=VALUE(VX)
      COSAPO=DOT(RX,VX)/(R*V)
C
C
C
 EVENT BOOST(SRCH1,CIRCLE)
 CRITERION (COSAPO=0.0)
C
      R1=ALT1*FTMILE+REGRAV
      CALL ALTER(R1)
C
C
      RSAV(1)=RX
      RSAV(2)=RY
      RSAV(3)=RZ
C
      PER2=PI*SQRT(((R+R1)**3)/(2*GME))
      TSRCH2=T+0.5*PER2-600.0
C
C
 EVENT SRCH2 (BOOST,CIRCLE)
 CRITERION(T=TSRCH2)
C
C
      CALL CROSS(RSAV, RX, QTEMP, 1)
      CALL CROSS(QTEMP, RSAV, TTEMP,1)
C
 AUXEQ
C
      RTEMP = DOT(TTEMP,RX)
C
 EVENT CIRCLE(SRCH2,STOP)
 CRITERION (RTEMP=0.0)
C
      R=VALUE(RX)
      CALL ALTER(R)
C
C
 AUXEQ
C
C
C
 EVENT STOP(S4OFF1)
 CRITERION(T=TSAV)
 LAST
 END
```

FIGURE 3

EOS Events List for the Simulation of an Earth-Orbit Trajectory

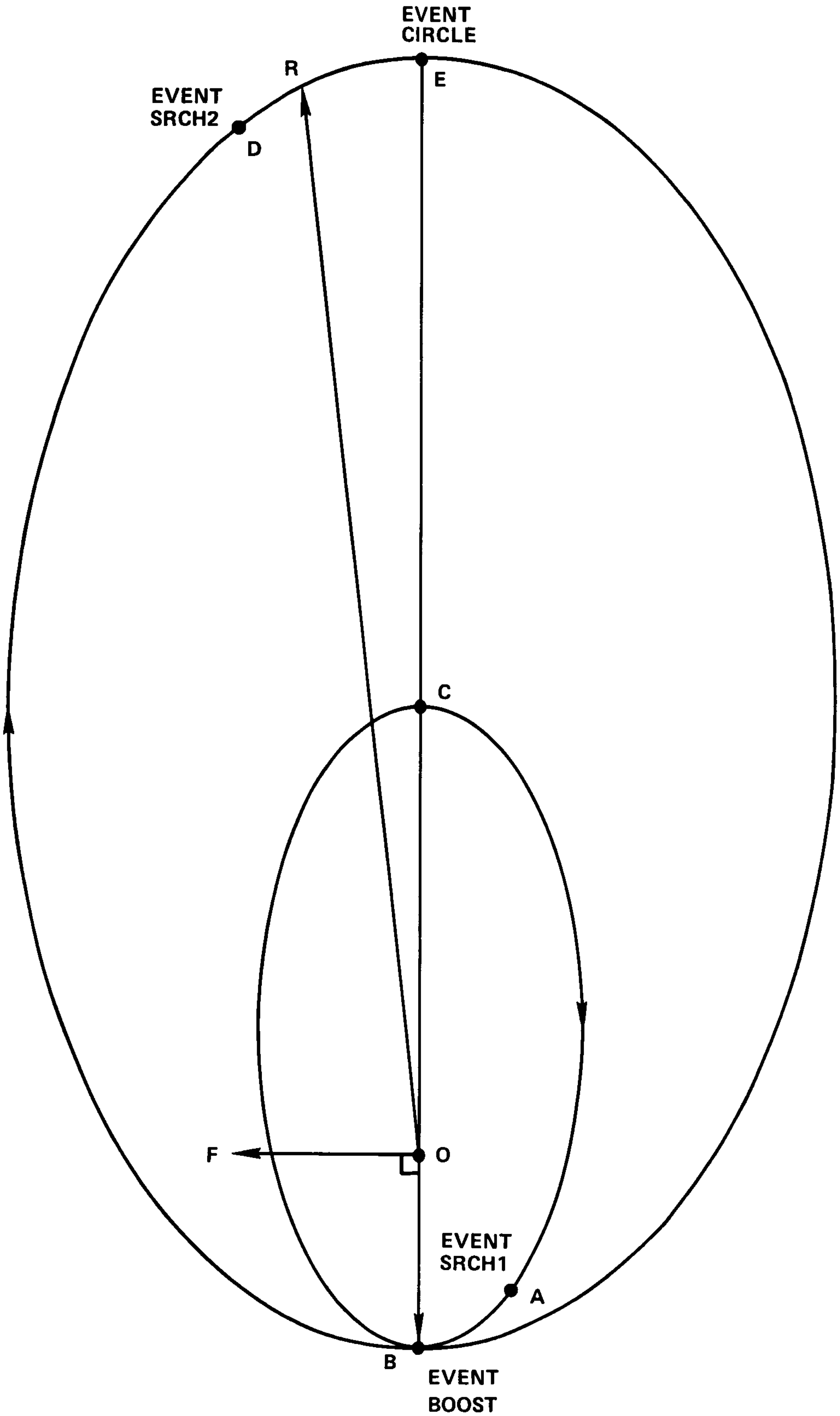

FIGURE 4 - RELATION OF EOS EVENTS TO A HOHMANN TRANSFER

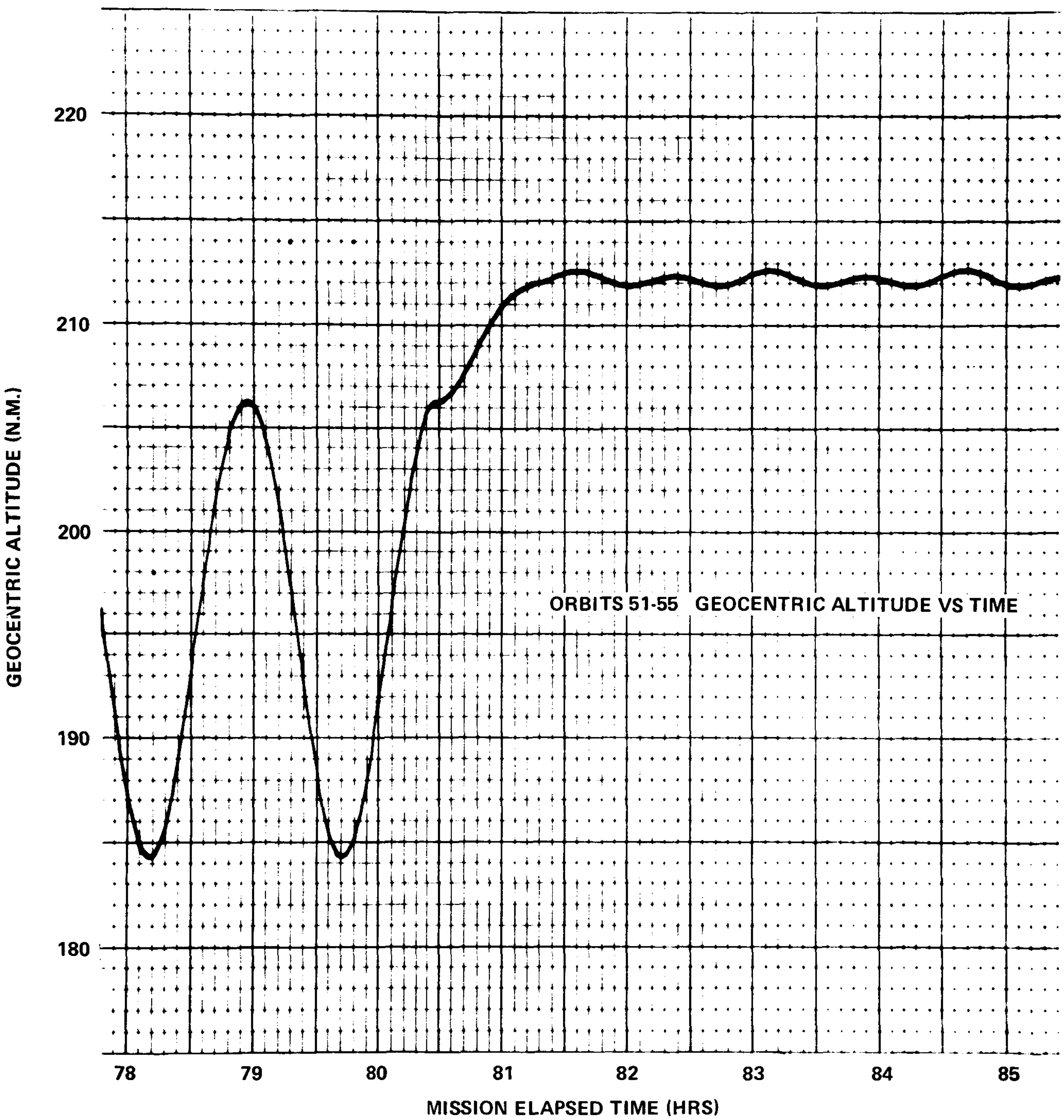

FIGURE 5 - SIMULATION OF MINIMUM ENERGY ORBIT TRANSFER

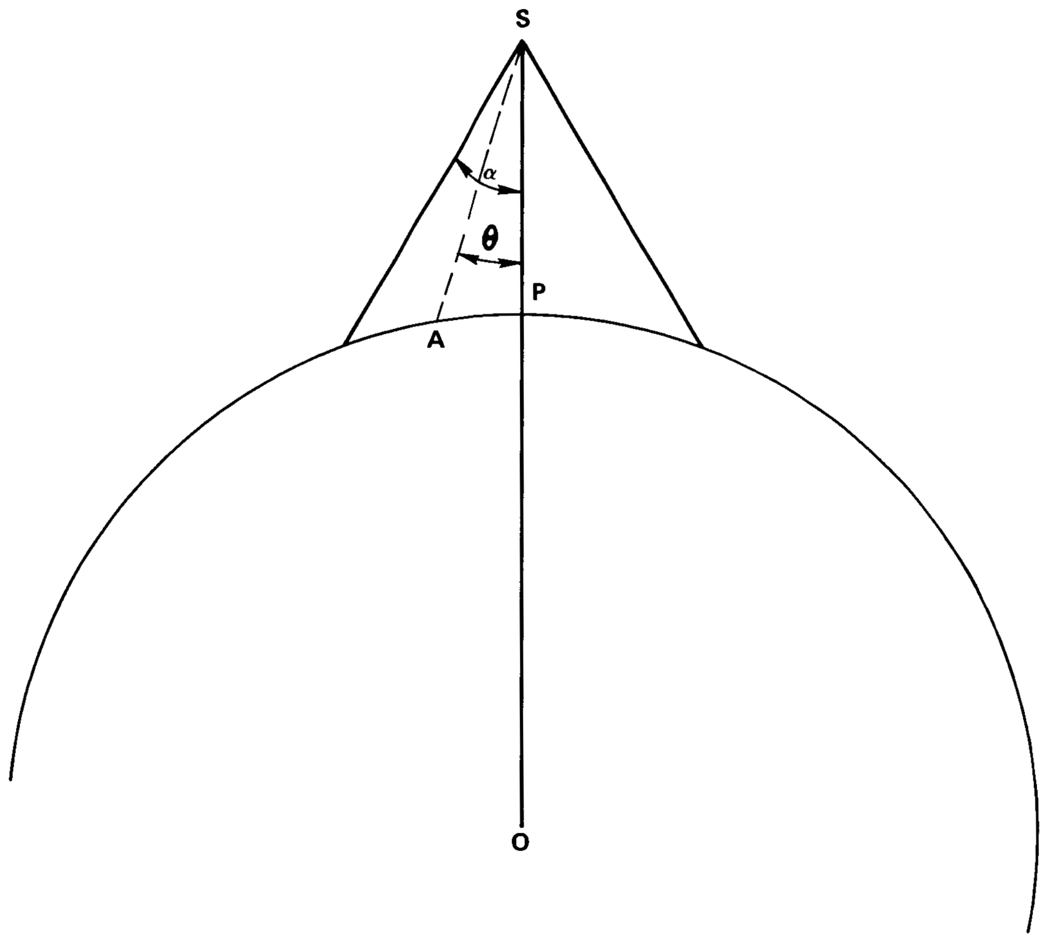

FIGURE 6a - VIEWING GEOMETRY FOR DETERMINING VISUAL CONTACT WITH PHOTOGRAPHIC TARGETS

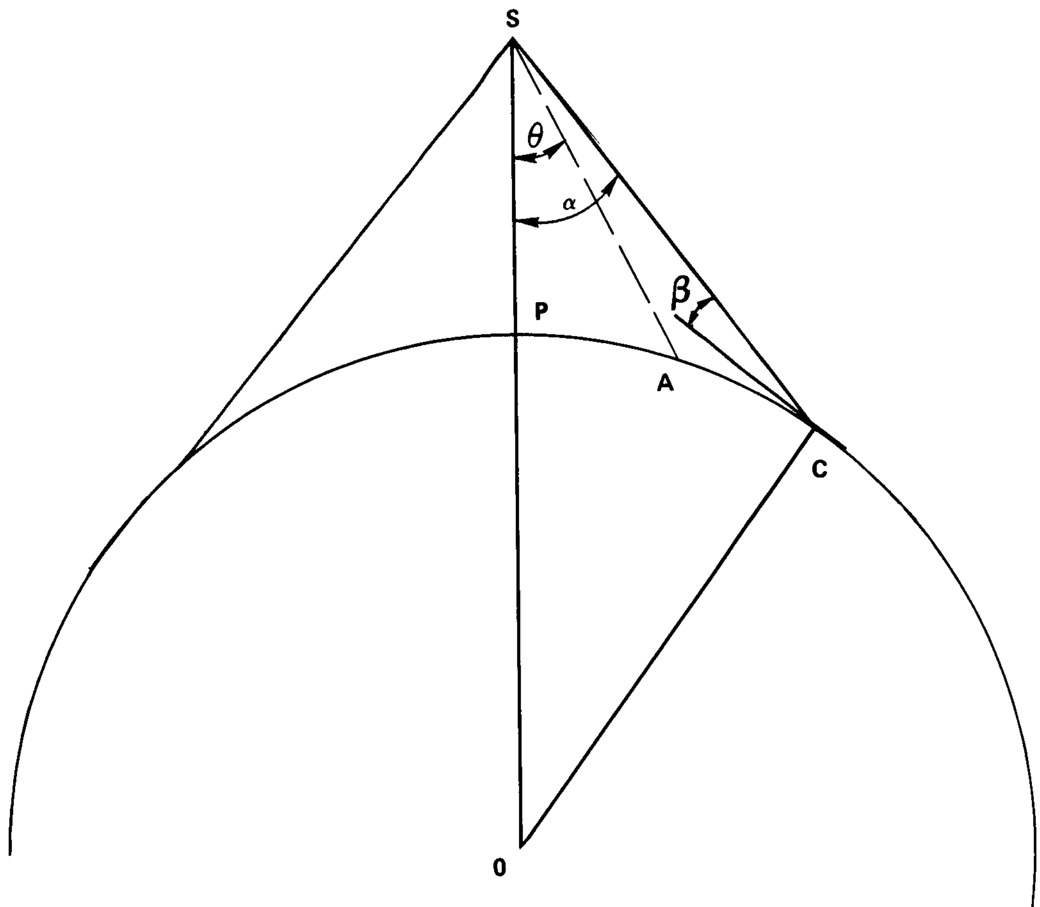

FIGURE 6b - VIEWING GEOMETRY FOR DETERMINING LINE-OF-SIGHT CONTACT WITH MSFN GROUND STATIONS

TABLE 1

Contents of File BCMASP*DIX1

Subroutines

*ALTER
CLOSED
DENSTY
DIFEQ
*DYNAMC
ETHORB
GEODET
INITAL
INTMAX
*MOD
OUTPUT
OUTTGT
PRTCOM
*QTHETA
READIN
ROLLBK
ROLLPT
SIMDKS
SIMOPN
SIMTGT
SITB
TAGS
TAPE
TRJSEL

MAP BCMASP

Card File Elements

COMMUN
DNCYCLE
OBTAIN
PHOTO
SCEPHEM

---

*Original Subroutine

TABLE 2

Card File Elements on File DIX1

Name	Purpose
COMMUN	Edit and recompile Subroutine OUTTGT to compute line-of-sight encounters with MSFN ground stations.
DNCYCLE	Edit and recompile Subroutine OUTTGT to compute spacecraft day/night cycles.
OBTAIN	Edit and recompile Subroutine SIMTGT and supply BCMASP data cards to initiate a targeting run.
PHOTO	Pick up and load the standard version of Subroutine OUTTGT to compute site visibility for photographic targets.
SCEPHEM	Edit and recompile Subroutine OUTTGT to calculate spacecraft subpoint position and altitude.

TABLE 3

Special Labeled COMMON

Fortran Name	Definition	Method of Input
Labeled COMMON Block BAKER		
DEPS	Maximum error in viewing angle (degrees)	NAMELIST
IPLOT	Flag controlling generation of spacecraft-target encounter tape	NAMELIST
M	Number of target sites to be investigated	NAMELIST
NAME(I,6)	Name of the ith target	Formatted Read
QANGLE	Maximum viewing angle (degrees)	NAMELIST
TPLAT(I)	Latitude of the ith target (degrees)	Formatted Read
TPLON(I)	Longitude of the ith target (degrees)	Formatted Read
Labeled COMMON Block NASH		
FTENB(44)	Predicted values of mean solar flux	NAMELIST
BASEYR	Time corresponding to FTENB(1) (years)	NAMELIST

APPENDIX

Tables A-1 and A-2 are dictionaries of the FORTRAN variables assigned to the CEOS COMMON block. Table A-1 lists the variables in alphabetical order and Table A-2 lists the variables in order of their storage locations.

TABLE A-1

CEOS COMMON Block Assignments in Alphabetical Order

FORTRAN Name	EOS #	Definition
ALT1	12	Required orbital altitude at the end of a Hohmann transfer (nm)
ARADOK	8	Cross-sectional area of the orbiting mass after the docking maneuver (square feet)
ARAINJ	5	Cross-sectional area of the orbiting mass at insertion (square feet)
CDDOK	7	Drag coefficient of the orbiting mass after the docking maneuver
CDINJ	4	Drag coefficient of the orbiting mass at insertion
DELTA	17	Convergence factor used in spacecraft weight optimization
DUMT	2	Mission time to the boundaries of encounter
GINCL	18	Inclination of osculating orbit plane (degrees)
GINCLR	19	Desired orbit inclination at insertion (degrees)
IDATA	27	Flag controlling the contents of the intermediate tape
IDAY	25	Gregorian Date of Launch
IOPTIN	30	Option Flag in Subroutine TRJSEL

FORTRAN Name	EOS #	Definition
ISKIP1	28	Printout switch in Subroutine TRJSEL
ISKIP2	29	Printout switch in Subroutine TRJSEL
IYEAR	23	Gregorian Year of Launch
ORBIT	1	Orbit Number
QGINCL	20	Maximum acceptable deviation of GINCL from GINCLR at insertion (degrees)
QMAX	21	Maximum aerodynamic pressure (pounds/sq in)
QMAXR	22	Reference value of QMAX used for preliminary trajectory shaping (pounds/sq in)
QMONTH	24	Gregorian Month of Launch
QWGT5	14	Tolerance on spacecraft weight optimization
RAPOGR	26	Desired apogee radius at insertion (feet)
TB	3	Mission elapsed time at one integration step after Event S4OFF1 (seconds)
TDOCK	10	Mission elapsed time for the execution of Event DOCK (seconds)
TSRCH1	11	Mission elapsed time for the execution of Event SRCH1 (seconds)
WGT2AA	15	S-IVB weight jettisoned at CSM/S-IVB separation (pounds)

FORTRAN Name	EOS #	Definition
WGTDOK	9	Weight of the orbiting mass after the docking maneuver (pounds)
WGTINJ	6	Weight of the orbiting mass at insertion (pounds)
WGTSC1	13	Weight of the spacecraft above the SLA (pounds)
WT1JET	16	S-IB weight jettisoned at S-IVB/SIB separation (pounds)

TABLE A-2

CEOS COMMON Block Assignments by Block Location

EOS #	FORTRAN Name	Definition
1	ORBIT	Orbit Number
2	DUMT	Mission time to the boundaries of encounter (seconds)
3	TB	Mission elapsed time at one integration step after Event S4OFF1 (seconds)
4	CDINJ	Drag coefficient of the orbiting mass at insertion
5	ARAINJ	Cross-sectional area of the orbiting mass at insertion (square feet)
6	WGTINJ	Weight of the orbiting mass at insertion (pounds)
7	CDDOK	Drag coefficient of the orbiting mass after the docking maneuver
8	ARADOK	Cross-sectional area of the orbiting mass after the docking maneuver (square feet)
9	WGTDOK	Weight of the orbiting mass after the docking maneuver (pounds)
10	TDOCK	Mission elapsed time for the execution of Event DOCK (seconds)
11	TSRCH1	Mission elapsed time for the execution of Event SRCH1 (seconds)

EOS #	FORTRAN Name	Definition
12	ALT1	Required orbital altitude at the end of a Hohmann transfer (nm)
13	WGTSC1	Weight of the spacecraft above the SLA (pounds)
14	QWGT5	Tolerance on spacecraft weight optimization
15	WGT2AA	S-IVB weight jettisoned at CSM/S-IVB separation (pounds)
16	WT1JET	S-IB weight jettisoned at S-IVB/SIB separation (pounds)
17	DELTA	Convergence factor used in spacecraft weight optimization
18	GINCL	Inclination of osculating orbit plane (degrees)
19	GINCLR	Desired orbit inclination at insertion (degrees)
20	QGINCL	Maximum acceptable deviation of GINCL from GINCLR at insertion (degrees)
21	QMAX	Maximum aerodynamic pressure (pounds/sq in)
22	QMAXR	Reference value of QMAX used for preliminary trajectory shaping (pounds/sq in)
23	IYEAR	Gregorian Year of Launch
24	QMONTH	Month of Launch
25	IDAY	Gregorian Date of Launch
26	RAPOGR	Desired apogee radius at insertion (feet)

EOS #	FORTRAN Name	Definition
27	IDATA	Flag controlling the contents of the intermediate tape
28	ISKIP1	Printout switch in Subroutine TRJSEL
29	ISKIP2	Printout switch in Subroutine TRJSEL
30	IOPTIN	Option Flag in Subroutine TRJSEL

BELLCOMM, INC.

Subject: Revisions to the BCMASP Earth-Orbit Simulator Program - Case 610

From: A. B. Baker

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